Nitrogen accumulation of six groups of sorghum grown on a municipal biosolids use site

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ABSTRACT: Groundwater contamination with nitrate (NO_3^-) is a current problem in the U.S. Sources of contamination include disposal of municipal biosolids. Because sorghum (*Sorghum bicolor* [L.] Moench) is an efficient scavenger of nitrogen (N) from the soil, its production on soils that receive biosolids may reduce N accumulation in those soils. An experiment was conducted to determine the amount of N accumulated by six types of sorghum. Three hybrids each of six types of sorghum (tropical, forage, sudangrass, sorghum × sudangrass, grain, and sweet) were evaluated for N accumulation on a municipal biosolids disposal site. Tropical sorghum and sorghum × sudangrass had the highest dry matter production and accumulated the most N. Nitrogen accumulation was largely a function of dry matter yield. Biomass produced was only adequate for beef maintenance diets but may be a useful biomass source for ethanol production from celulose. *Water Environ. Res.*, **67**, 1076 (1995).

KEYWORDS: animal feed, biosolids, nitrate, nitrogen, sorghum, use.

Throughout the U.S. large quantities of municipal, industrial, and livestock wastes that contain N and other potential groundwater pollutants are generated each year. Land application of municipal biosolids is a viable alternative to incineration or landfilling and represents the useful recycling to the biosphere of nutrients present in biosolids. A major concern associated with land application of municipal biosolids is the potential for excessive N loading and subsequent groundwater contamination (Walker, 1989). Under favorable conditions a substantial portion of the N is rapidly mineralized and nitrified and becomes available for leaching into the groundwater. The fate of this N is essentially a function of the manner in which the land is subsequently managed. Certainly, the N from organic wastes can be safely used within traditional cropping systems if the soil is not loaded with N beyond the ability of the crop to remove it.

An ideal cropping system for recycling N from biosolids should be able to remove very large amounts of N from the profile quickly and allow for multiple biosolids applications during the growing season. Sorghum, or sorghum × sudangrass hybrids, grown for forage are crops likely to realize these ideals. Sorghum has a very high N uptake potential and an extensive root system that is very effective in scavenging N from the soil (Long, 1981; Myers, 1980). In California, Worker and Marble (1968) reported that sorghum × sudangrass hybrids yielded an average of 35.6 Mg/ha and accumulated 387 kg N/ha when harvested at the soft dough stage of development. When harvested at the flowering stage, average yields were 36.6 Mg/ha and N accumulation exceeded 500 kg N/ha. Burger and Hittle (1967) reported sorghum × sudangrass yields in excess of 16 Mg/ha in Illinois, with total N accumulation over 400 kg N/ha under a three-cut system.

The specific objectives of the research reported herein were to evaluate diverse sorghum genotypes for N accumulation on an actual biosolids use site and to assess the usefulness of the forage produced on that site for use in livestock systems.

Methodology

Three commercially available hybrids each of a grain sorghum, sweet sorghum, forage sorghum, tropical sorghum, sudangrass, and sorghum × sudangrass (Table 1) were grown at the Northeast Waste Water Treatment Plant Biosolids Injection Site, Lincoln, Nebraska, in 1990 and 1991. Before biosolids injection, the sites had 20 kg NO_3-N/ha residual in the top 15 cm of soil. Biosolids were injected 9 April and 22 April 1990 at a cumulative total N rate of 410 kg/ha, and 1 April and 14 April 1991 at a cumulative total N rate of 390 kg/ha. The site was prepared for planting by field cultivating and was planted 4 June 1990 and 31 May 1991. Plots were two 7.6-m-long rows on 76-cm centers. The design was nested and replicated four times. Hybrids were nested within types, and two border rows of Piper sudangrass were planted between each type to reduce border effects due to differences in height. Propachlor [2-chloro-N (1-methylethyl)-N-phenylaetamide/Atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5,-triazine-2,4,-diamine]] was applied at 9.4 L/ha immediately after planting for weed control. Stands were hand thinned to approximately 75 000 plants/ha.

Immediately before harvest, maturity scores were taken for each plot according to Moore *et al.* (1991). One row of each plot was hand harvested to a 3-cm stubble height on 25 September 1990 and immediately weighed and chopped with a commercial wood chipper. In 1991, one row of each plot was harvested on 18 September with a commercial forage cutter modified with an electronic weigh bucket. Entire rows were harvested and chopped in each year. Subsamples were taken for dry matter and laboratory analyses. Total N concentration was determined by macro Kjeldahl (AOAC, 1980) and NO_3^- concentration by cadmium reduction (Fishman and Friedman, 1985) on a Lachat flow injection analysis system. Crude protein (CP) was calculated as 6.25 × N concentration. In vitro dry matter disappearance (IVDMD) was determined according to Marten and Barnes (1980).

Several assumptions were made in this study. It was assumed that N availability from soil amended with biosolids was equal across treatments, allowing valid comparisons of N accumulation among sorghum types and hybrids. It was also assumed that N accumulated by the sorghum was not fixed by the plant or mi-

Table 1—Source of sorghum hybrids grown on the Lincoln, Nebraska, municipal wastewater biosolids use site in 1990 and 1991.

Type	Hybrid	Source
Grain sorghum	DK41Y	Dekalb
	8358	Pioneer
	G550E	Funk's
Sudangrass	Trudan 8	Northrup King
	Monarch V	Vista
	Piper*	—
Sorghum × sudangrass	GreenTreat II	Vista
	ST-6E	Dekalb
	FP5	Funk's
Forage sorghum	DorGo 10	Vista
	FS-1 at	Dekalb
	102F	Funk's
Sweet sorghum	Sucrosorgo 301	Northrup King
	Sweetreat	Vista
	FS-25 E	Dekalb
Tropical sorghum	Sucrosorgo 405	Northrup King
	G1990	Funk's
	911	Pioneer

* Piper is a public variety, not a hybrid.

Table 2—Combined year data for dry matter yield, nitrogen concentration, and nitrogen accumulation for sorghum grown on the Lincoln, Nebraska, municipal water biosolids use site in 1990 and 1991.

Type	Hybrid	Dry matter yield, mg/ha	Nitrogen concentration, g/kg	Nitrogen accumulated, kg/ha
Grain sorghum	DK41Y	12.7	15.1	191
	8358	14.8	14.8	214
	G550E	13.0	16.0	208
Mean		13.5	15.3	204
Sudangrass	Trudan 8	18.6	12.8	238
	Piper*	13.7	13.7	190
	Monarch V	14.6	13.6	197
Mean		15.6	13.4	208
Sorghum × sudangrass	GreenTreat II	20.7	12.9	271
	ST-6E	20.6	12.2	251
	FP5	17.2	13.1	229
Mean		19.5	12.7	251
Forage sorghum	SorGo 10	11.9	13.6	161
	FS-1 at	18.8	14.8	278
	102F	20.7	13.4	279
Mean		17.1	14.0	240
Sweet sorghum	Sucrosorgo 301	14.6	13.1	191
	Sweetreat	11.6	11.8	137
	FS-25 E	21.1	13.3	280
Mean		15.8	12.7	203
Tropical sorghum	Sucrosorgo 405	22.2	12.7	283
	G1990	17.9	14.7	263
	911	18.2	14.1	252
Mean		19.4	13.8	266
SE (within types)		1.21	0.5	19
SE (among types)		.701	0.3	11

Source	df	Analysis of Variance		
Year	1	†	NS	NS
Type	5	†	†	†
Year × type	5	NS	NS	NS
Hybrid (type)	12	†	†	†
Year × hybrid (type)	12	NS	NS	NS

† Significant at the 0.05 level of probability; NS, not significant ($P > 0.05$).

* Piper is a public variety, not a hybrid.

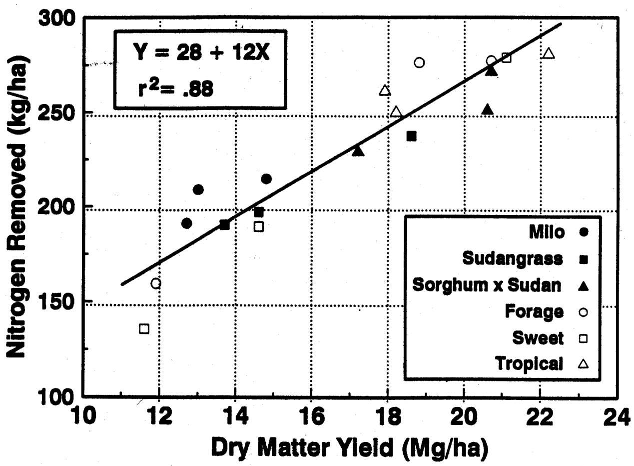

Figure 1—Nitrogen accumulation vs. dry matter yield of sorghum hybrids grown on the Lincoln, Nebraska, municipal wastewater biosolids use site in 1990 and 1991.

crobial symbiants (a potentially confounding factor). Although symbiotic N fixation can occur in sorghum, the relative amounts reported in field studies (Subba *et al.,* 1984) are insignificant compared with N accumulation in this study. Furthermore, symbiotic N fixation would be expected to be inhibited by the high levels of N augmentation used in this study (Wani, 1984; Alexander and Zuberer, 1989). Because of the above, and the difficulty in balancing N in highly organic systems, no measurement of N remaining in the soil after the experiments was made to determine N removal from the soil. As stated earlier, our objective was to compare sorghum types and hybrids on a uniform, working biosolids use site.

Results

With the exception of the tropical sorghums, all sorghum types and hybrids had reached at least soft dough at harvest, and maturity scores were similar (data not shown). Within the tropical sorghums, Northrup King Sucrosorgo 405 reached soft dough in 1990 but only reached anthesis in 1991. Funk's G1990 and Pioneer 911 remained vegetative until harvest in both years. Significant ($P \leq 0.05$) year interactions for growth stage were detected for sorghum type and for hybrids within type, predominantly because of the difference in maturity of Northrup King Sucrosorgo 405 at harvest in 1990 and 1991.

As expected, tropical sorghums had high dry matter yield (19.4 Mg/ha). However, sorghum × sudangrass hybrid dry matter yields were not significantly different ($P \leq 0.05$) from tropical sorghums using an F-protected least-significant-difference test (Table 2). Significant differences were detected among hybrids within sorghum type. Wide variation in dry matter yield within sudangrass, sweet sorghum, and tropical sorghum hybrids were observed. Sorghum × sudangrass hybrids exhibited consistently high dry matter yield (19.5 Mg/ha), whereas grain sorghum hybrids exhibited consistently low dry matter yields (13.5 Mg/ha). One sweet sorghum entry, Dekalb FS-25-E, had a very high dry matter yield (21.1 Mg/ha), whereas the other sweet sorghums were relatively low yielding. Similarly, one sudangrass, Northrup King Trudan 8, had a very high dry matter yield (18.6 Mg/ha), whereas the other sudangrasses were relatively low yielding.

Nitrogen accumulated by a crop is a function of dry matter yield and N concentration of the dry matter. Significant differences in N concentration were shown for sorghum type and hybrid within type (Table 2). However, differences in N concentration were generally small. Grain sorghum hybrids exhibited the highest N concentration, which was probably due to the higher N concentration of their relatively greater grain component.

Maximum N was accumulated by tropical sorghums, forage sorghums, and sorghum × sudangrass hybrids (266, 240, 251 kg/ha, respectively). Hybrid effects within type were significant for N accumulation but appeared to be largely a function of differences in dry matter yield as evidenced by the high N accumulation of FS-2S E sweet sorghum (280 kg N/ha) and Trudan 8 sudangrass (238 kg N/ha). Although considerable genetic and morphological diversity existed among the hybrids tested, the relationship between N accumulated and dry matter yield was linear (Figure 1) ($r^2 = 0.88$, $P \leq 0.05$).

A major concern for livestock producers using the forage produced on a high N biosolids use site is the potential for nitrate poisoning. Sorghum type and hybrid within type effects were significant for NO_3^- concentration (Table 3). Tropical sorghums averaged 2344 mg NO_3-N/kg which is higher than the 2 100 mg/kg recommended threshold for feed safety (Rasby *et al.,* 1988). Forage sorghum and sorghum × sudangrass hybrids and sudangrass averaged 1982, 1501, and 1561 mg NO_3-N/kg, respectively. However, individual hybrids within the forage sorghums and sorghum × sudangrasses exceeded the 2100 mg NO_3-N/kg limit, and two sudangrass hybrids approached the 2 100 mg/kg NO_3-N limit. Grain sorghum and notably sweet sorghums including FS-25E had relatively low NO_3-N concentrations. Because a single instance of feeding toxic feedstuffs could be devastating to a livestock producer, it would appear prudent to test any forage produced on a high N biosolids use site for NO_3^- concentration on a case by case basis or ensile the forage (Rasby *et al.,* 1988) to lessen the likelihood of NO_3^- poisoning.

Significant type and hybrid within type effects were detected for *in vitro* dry matter disappearance (IVDMD) and crude protein (CP) concentration (Table 3). Year interactions were significant but probably attributable to the maturity differences between Northrup King Sucrosorgo 405 and the other two tropical sorghums. However, most importantly, no entries in either year were sufficiently high in IVDMD or CP concentration to be considered high-quality feeds (individual data not shown). All would be adequate for use as a maintenance diet for dry gestating cows, or as a source of roughage in mixed rations, unless toxic levels of NO_3-N are present. Solely on the basis of chemical composition, grain sorghum and sweet sorghum hybrids provided the highest quality feed. Both had relatively low NO_3-N concentration and were among the highest in IVDMD. However, as a group, they were also among the lowest in biomass yield.

Discussion

Dry matter yields of nearly 10 Mg/ha and N accumulation of 251 kg/ha from sorghum × sudangrass hybrids presents an opportunity for rapid development of a forage-based alternative for biosolids use. Sorghum × sudangrass hybrids are currently widely used for forage in much of the central U.S. Contacts and inquiries from commercial biosolids disposal operations in the region indicate that a major problem is a lack of available land for biosolid application during the cropping season. In addition to providing excellent biomass yields and N accumulation potential, sorghum × sudangrass hybrids offer the option of mul-

Table 3—Combined year data for in vitro dry matter disapperance (IVDMD), crude protein, and nitrate concentration for sorghum grown on the Lincoln, Nebraska, municipal wastewater biosolids utilization site in 1990 and 1991.

Type	Hybrid	IVDMD, g/kg	Crude protein, g/kg	Nitrate, mg/kg
Grain sorghum	DK41Y	623	94.4	1 099
	358	600	92.2	1 609
	G550E	670	99.9	886
Mean		631	95.5	1 198
Sudangrass	Trudan 8	550	80.0	1 129
	Piper*	471	85.8	1 808
	Monarch V	485	84.8	1 747
Mean		502	83.5	1 561
Sorghum × sudangrass	GreenTreat II	520	80.6	1 155
	ST-6E	499	76.4	2 109
	FP5	540	82.1	1 239
Mean		519	79.7	1 501
Forage sorghum	SorGo 10	610	85.0	1 634
	FS-1 at	624	92.8	2 646
	102F	582	84.1	1 665
Mean		605	87.3	1 982
Sweet sorghum	Sucrosorgo 301	604	82.1	812
	Sweetreat	610	73.8	787
	FS-25 E	578	82.8	1 006
Mean		598	79.5	869
Tropical sorghum	Sucrosorgo 405	542	78.6	1 997
	G1990	555	102.3	2 453
	911	531	88.3	2 583
Mean		542	89.8	2 344
SE (within types)		18	3.4	289
SE (among types)		10	2.0	167

Source	df	Analysis of Variance		
Year	1	NS	NS	NS
Type	5	†	†	†
Year × type	5	†	NS	NS
Hybrid (type)	12	†	†	†
Year × hybrid (type)	12	NS	NS	NS

* Piper is a public variety, not a hybrid.
† Significant at the 0.05 level of probability; NS, not significant ($P > 0.05$).

tiple harvests throughout the growing season, which, in turn, would allow for multiple applications of biosolids to a site during a single crop year. Their use as forage where biosolids are high in heavy metal concentration would require periodic testing of forage for metal content (Chang *et al.*, 1983).

In addition to their value for livestock production, sorghum produced in biosolids use systems could be used as a feedstock for ethanol fuel production from biomass (Lynd *et al.*, 1991). Sorghum × sudangrass hybrids have been specifically identified as a crop with high potential for production of ethanol from cellulosic biomass (Cherney *et al.*, 1988). Nutritional quality and NO_3-N levels in the biomass would be of little consequence as a feedstock for ethanol production.

The number of hybrids representing each sorghum type in this study is small. Many other hybrids will undoubtedly perform as well, or better than some of the hybrids used in this study. Because N accumulation appears to be largely a function of biomass yield, selection of hybrids exhibiting high biomass yield for inclusion in organic waste disposal systems would appear most appropriate if the major objective was maximum N removal. Likewise, if hybrids were to be developed specifically for biosolids use systems, geneticists would probably maximize progress by concentrating their efforts on biomass yield.

Summary and Conclusions

Sorghum × sudangrass hybrids and tropical sorghum hybrids were shown to accumulate up to 250 kg/ha N on a municiple biosolids use site in the central U.S. Tropical sorghum hybrids can be selected that remain vegetative in that region and thereby eliminate any threat of undersired volunteering in subsequent years. Sorghum × sudangrass hybrids allow more flexible management, however, and can be harvested several times during the growing season (although not done in this study). Such management would enable multiple applications of biosolids during the growing season.

The sorghum biomass produced on this biosolid disposal site was adequate in quality for cattle maintenance diets. It also was at times sufficiently high in NO_3 concentration to be toxic to livestock. Alternative uses of such biomass, including its use as a feedstock for ethanol production, should be considered.

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References

Alexander, D. B., and Zuberer, D. A. (1989) Impact of Soil Environmental Factors on Rates of N2-Fixation Associated with Roots of Intact Maize and Sorghum Plants. In Nitrogen Fixation with Non-Legumes. F. A. Skinner, R. M. Boddey, I. Fendrik (Eds.), Kluwer Academic Publishers, Dordrecht, Boston, London, 273–285.

Association of Official Agricultural Chemists (1980) Official Methods of Analyses of the AOAC, 9th ed. Association of Official Agricultural Chemists, Washington, D.C.

Burger, A. W., and Hittle, C. N. (1967) Yield, Protein, Nitrate, and Prussic Acid Content of Sudangrass, Sudangrass Hybrids, and Pearl Millets Harvested at Two Cutting Frequencies and Two Stubble Heights. *Agron. J.,* **59,** 259.

Chang, A. C., Page, A. C., Warneke, J. E., Resketo, M. R., and Jones, T. E. (1983) Accumulation of Cadmium and Zinc in Barley Grown on Sludge-Treated Soils, a Long-Term Field Study. *J. Environ. Qual.* **12,** 391.

Cherney, J. H., Johnson, K. D., Volenec, J. J., and Anliker, K. S. (1988) Chemical Composition of Herbaceous Grass and Legume Species Grown for Maximum Biomass Production. *Biomass,* **17,** 215.

Fishman, M. J., and Friedman, L. C. (1985) Methods for Determination of Inorganic Substances in Water and Fluvial Sediments, Book 5, Chap. A1. U.S. Department of Interior, U.S. Geological Survey, Washington, D.C.

Long, Leslie F. (1981) The Influence of Sorghum-Sudangrass Roots on Nutrient Leaching. *Agron. J.,* **73,** 537.

Lynd, L. E., Cushman, J. H., Nichols, R. J., and Wyman, C. E. (1991) Fuel Ethanol from Cellulosic Biomass. *Science,* **251,** 1318.

Marten, G. C., and Barnes, R. F. (1980) Prediction of Energy Digestibility of Forages with *in vitro* Rumen Fermentation and Fungal Enzyme Systems. In *Proc. Int. Workshop on Standardization Anal. Methodology Feeds.* W. J. Pigden *et al.* (Eds.) IDRC-134e. Ottawa, Canada 12014 March 1979. International Development Research Centre, Ottawa, Canada, 61–71.

Moore, K. J., Moser, L. E., Vogel, K. P., Waller, S. S., Johnson, B. E., and Pedersen, J. F. (1991) Describing and Quantifying Growth Stages of Perennial Forage Grasses. *Agron. J.,* **83,** 1073.

Myers, R. J. K. (1980) The Root System of a Grain Sorghum Crop. *Field Crops Res.,* **3,** 53.

Rasby, R., Stock, R., Anderson, B., and Schneider, N. (1988) Nitrates in Livestock Feeding. NebGuide G74-170. Cooperative Extension Service Institute of Agriculture and Natural Resources University of Nebraska-Lincoln.

Subba Rao, N. S., Tilak, K. V. B. R., Singh, C. S., and Nair, P. V. (1984) Yield and Nitrogen Gains of Sorghum as Influenced by Azospirillum brasilense. In Cereal Nitrogen Fixation. S. P. Wani (Ed.). *Proceedings of the Working Group Meeting, India,* October 9–12, ICRISAT Center, India. Patancheru, A. P. 502324, India:ICRISAT, 69–76.

Walker, J. M. (1989) Assessment of Sludge Regulation Assumptions: A Framework for Analysis. *Biocycle,* **30,** 71.

Wani, S. P. (1984) Research on Cereal nitrogen fixation at ICRISAT. In Cereal Nitrogen Fixation. S. P. Wani (Ed.). *Proceedings of the Working Group Meeting, India,* October 9–12, ICRISAT Center, India. Patancheru, A. P. 502324, India:ICRISAT, 55–68.

Worker, G. F., Jr., and Marble, V. L. (1968) Comparison of Growth Stages of Sorghum Forage Types as to Yield and Chemical Composition. *Agron. J.,* **60,** 669.